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Smart cargo container tracking and IT security management: Experimental results

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ABSTRACT

The paper presents an experimental study dealing with the tracking of a cargo container including its state in real time. For this study, the device that is attached to the inside of the container door is conceived, designed and created. A 'do-it-yourself principle' is used to get a better insight into the behavior of the device during transport and to facilitate later upgrades and further research. The central component of the tracking device is a Raspberry Pi computer. The accompanying appliances are a power source (battery) supported by an uninterruptible power supply (UPS) unit, a Global System for Mobile (GSM) communications modem, a Global Positioning System (GPS) transceiver, a server, a dispatcher/user desktop computer and a virtually smartphone. Five types of sensors for continuous scanning of temperature, humidity, light, tilt and time are included to check the status of conditions inside the container. The dispatcher and user interfaces are provided by a secure web application programmed in Python. The motive for carrying out this experiment was our research curiosity triggered by the existing gap in the mechanisms for tracking a single freight container in the block of containers loaded into a container ocean carrier, for instance. At this stage, the experiment is realized in road transport. It is currently in the process of being 'cloned' for maritime transport, as there are some administrative obstacles to obtaining research ethics approval.

While it is not always necessary to track every container in transit, when it comes to dangerous, perishable and high specific value cargo, tracking a single container is recommended for several reasons, including visibility, efficiency, safety and security. As part of the environmental scan, some comparisons are made with existing systems for tracking drums or casks of nuclear cargo in land and sea transport. As the experiment includes a web-based interface and back-end info-communication system, some precautions for Information Technology (IT) security management are briefly considered, as well.

1. Introduction.

The statistics show that there are approximately 65 million cargo containers in operation today [1]. However, only 5.6% of them are equipped with telematics devices to record and transmit their position, status and cargo condition inside in real time. This percentage is increasing, and it is predicted that by 2027, 30% of the containers in operation will have built-in telematics devices [2]. Why? - So called smart containers help correctly manage the supply chain and logistics, provide up-to-date data tracking, and forecast the time of arrival at port. They reduce paperwork and human dependency by enabling more precise and safe transport [3]. In 2017-2019, e.g., 779 containers were lost, whilst in 2020-2021 this number increased to 3 113. On top of this, about 20 billion US dollar is spent per year on empty containers replacements [4]. Therefore, tracking of containers is important for the optimal use of empty containers, storage, stuffing, loading-on and -off, delivery, etc., but also for monitoring and controlling the conditions inside the container. This is

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particularly significant if one deals with dangerous, perishable and/or high specific value cargoes. In such circumstances, it is recommendable to follow each container separately, in parallel with the physical conditions inside it, including cargo conditions. This is much easier to achieve on land than at sea. There are many reasons for this: the Internet at sea is not as stable and fast as on shore due to sea water surface movements, occlusion of waves, usually harsh weather conditions, 'urban canyon' effects, multipath fading, etc. In addition, while overland containers are usually lined up one after the other along the route, containers shipped by sea are loaded in huge blocks, which sometimes can count 24,000 twenty-foot equivalent units (TEUs) [5], e.g. More specifically, in maritime transport, containers are placed side by side in multiple levels in ship's hull and on board. As a result, accessing and collecting data from such arrangements is difficult. The situation is less complex with sea transport of radioactive load, for instance. The ships built for this purpose can only carry about twenty casks or drums of special construction adapted for transport of radioactive materials [6,7]. Although it is much easier to track containers separately in this arrangement, information on casks status is sent manually to the main tracking center onshore occasionally; not automatically, in real time.

The secondary sources [8-13] presented the solutions based on Radio Frequency Identification (RFID) devices for tracking containers with radioactive materials in road and rail transport. This technology includes an RFID tag/chip, a seal sensor, a set of sensors for tracking the container position and status, a positioning device, and a graphical user interface. In reference [14], a similar system that responds to a critical situation during the transport of containerized radioactive cargo is presented. This system includes sensor unit, communication network, central monitoring system and control subterminal that provides actual status, trends, and early detection of anomalies. These systems are used in land transport. However, there is a gap in tracking and tracing the position and status of containers while they are at sea. Sources [15,16] presented a prototype for monitoring casks with nuclear load in maritime transport at rather high level of abstraction. Later, a 'do-it-yourself' device for tracking freight containers in onshore and marine transport has been proposed [17]. As an extension of this research, additional experiments have been carried out, and presented in this article.

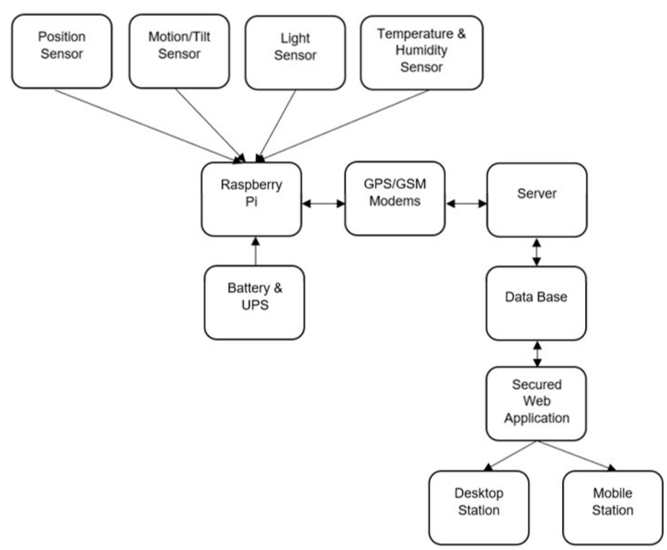
It is to be highlighted that numerous advanced experiments on tracking and tracing assets in open and closed spaces have been carried out so far [18]. Some experiments with modular, easily interlocked chipped containers are presented in [19]. Additionally, experiments combining containers equipped with (UHF) RFID chips and smart contracts in the blockchain environment have been carried out [20-22]. Despite these advanced research approaches, this article provides the results obtained through rather a simple practical experiment that can provide a clear comprehension of the system behavior in real conditions, including both on- and off-shore transport.

The following parts of the paper deals with the construction of the device proposed for tracking freight container (Part 2); Python code developed for data collection, storing, processing and presenting (Part 3); the results obtained ashore, before 'cloning' the experiment at sea environment (Part 4); cybersecurity concerns and IT security management (Part 5); along with the conclusions and plans for further experiments (Part 6).

2. Freight container tracking device.

Notwithstanding the existence of various solutions for container tracking, this paper presents a 'do-it-yourself' approach in tackling this problem. The proposed device consists of the Raspberry Pi (6GB RAM, 64GB card), common power supply, plus UPS. The Raspberry Pi is linked to GSM & GPS modems, and central computer. The central computer has links to desktop device and virtually smart phone (mobile device) via the secure web-based application. Data collection, processing, alarm setting and triggering is arranged on the server side. The main computer (Raspberry Pi) is also linked to the sensors for scanning: Sensor 1 - temperature, Sensor 2 - humidity, Sensor 3 - lightness, Sensor 4 – tilt or motion, and Sensor 5 - time. The conceptual model of the device is shown in Figure 1. The components used are easily available on the market, and inexpensive. Thanks to the applied physical computing concept, these components are effectively connected in both real and virtual environments.

Figure 1: Freight container tracking device architecture.

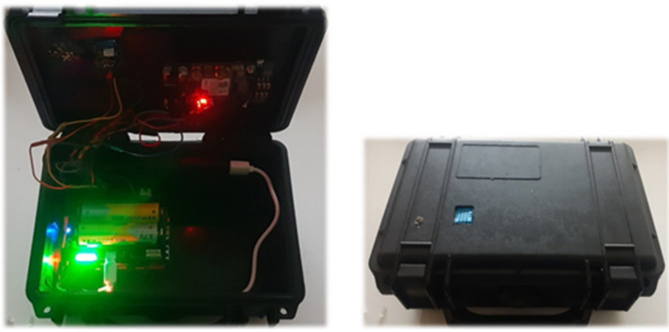


Source: Authors.

For the purposes of the experiment, the limits of the sensors are set as follows: the tilt sensor is preprogrammed to activate the alarm if the container moves more than fifteen (degrees) from perpendicular position. The temperature and humidity sensors are set to continuously scan the temperature and humidity conditions inside the container. These sensors send data to the server in (degree Celsius) and (%). If the container is opened during transport, the system triggers light alarm. As a unit for light sensor, lux is used. It is assumed that the container is closed during transport and that it is dark inside. Unplanned opening of the container's door along the journey instigates the alarm. The alarms, in general, warn the dispatcher of undesirable changes in the sensor parameters.

The device, at the final stage of its development, is shown in Figures 2.

Figure 2: Tracking device outside appearance.



Source: Authors.

The dimensions of the instrument are 16 cm (length), 12 cm (width) and 6 cm (height). It is mounted inside container's door to reduce interference during the voyage and avoid damages.

3. Python pseudo code.

Python is a popular, objective oriented language, which has been used for setting and running the application. This advanced programing language is flexible and supports procedural, object-oriented, and functional programming [23]. Regarding procedural programming, Python enables reading data and sending them to the data base at host. On another side, when it comes to functional programming it allows defining the alarms values and their activation, when boundary values are exceeded. Python enables communication between sensors, Raspberry Pi, and dispatcher-user through the application programming interface (API). Python pseudo code, which allows picking up sensors' values and directing them towards the data base is presented in Figure 3. Besides these functions, Python contains lines of code for controlling sensors' parameters limits. These data are regularly sent to the data base.

The device is probed onshore during the trip from Subotica (Vojvodina, Republic of Serbia) to Podgorica (Republic of Montenegro). Precisely, the container has been transported by the truck. In the later stage of our research work, the device will be probed at sea, on the ship route from the Port of Bar (Republic of Montenegro) to the Port of Bari (Italy). Currently, obtaining a research ethical clearance is in the process.

4. The results of the experiment.

Through the experiment, the digital stamp (id), geolocation, along with the data on temperature (Sensor 1), humidity (Sensor 2), lightness (Sensor 3), on inclination or tilt (Sensor 4) and time (Sensor 5) are collected. Along the route being studied, the container was opened as a part of the experiment, causing changes in lightness, while these changes were recorded and triggered the alarm. The tilt sensor reacted during loading and unloading operations. If the tilt limit was exceeded, it sent an output of 'zero'. Otherwise, it sent an output of 'one'. Each recorded data has its 'id' (Stamp). The results obtained along the route from Subotica to Belgrade are presented in Table 1.

Figure 3: A segment of the pseudo code in Python.

```
(...) import RPi.GPIO as GPIO
import sqlite3
import time
from datetime import date, datetime, timedelta

def get_db_connection():
   # Connection with the DB
   con = sqlite3.connect('rpi_sensor.db', timeout = 10)
   return con

def lightSensor():
   # Function that reads Light Sensor value and sends it back to the DB
   GPIO.setmode(GPIO.BOARD)
   light_sensor_pin = 22
   count = 0
   GPIO.setup(light_sensor_pin, GPIO.OUT)
   GPIO.output(light_sensor_pin, GPIO.LOW)
   GPIO.setup(light_sensor_pin, GPIO.IN)
   while (GPIO.input(light_sensor_pin) == GPIO.LOW):
      count += 1
   GPIO.cleanup()
   return count

def tiltSensor():
   # Function that reads Tilt Sensor value and sends it back to the DB
   GPIO.setmode(GPIO.BOARD)
   tilt_sensor_pin = 21
   tilt_led_pin = 40
   GPIO.setup(tilt_led_pin, GPIO.OUT)
   GPIO.setup(tilt_sensor_pin, GPIO.IN)
   current_tilt_state = 0
   current_tilt_state = GPIO.input(tilt_sensor_pin)
   GPIO.cleanup()
   return current_tilt_state

def temperatureHumiditySensor():
   # Function that reads Temperature & Humidity Sensor values and send these back to the DB
   import board
   import adafruit_dht
   import psutil

   for proc in psutil.process_iter():
      if proc.name() == 'libgpiod_pulsein' or proc.name() == 'libgpiod_pulsei':
         proc.kill()

   sensor = adafruit_dht.DHT11(board.D23)
   temp, humidity = None, None
   try:
      temp = sensor.temperature
      humidity = sensor.humidity
   except RuntimeError as error:
      time.sleep(1.5)
   except Exception as error:
      sensor.exit()
   time.sleep(1)
   GPIO.cleanup()
   return temp, humidity (...)
```

Source: Authors.

As we already mentioned, in the next phase of the experiment, the container will be transported by a patrol boat from the Port of Bar (Republic of Montenegro) to the Port of Bari (Italy). In the first iteration, the container will be on deck, within the range of satellite antenna, and in the second iteration it will also be on deck, but out of the antenna range. This will provide an insight into the quality of the signal and the accuracy of the position and state of the container and its load in both considered cases. A similar experiment will be repeated with a container placed below the deck, i.e., inside the ship's hull and exposed to the effects of the ship's propulsion, steering, and other Operation Technology (OT) systems and devices.

Table 1: The results gained along the route: Subotica - Belgrade (4^{th} May 2023).

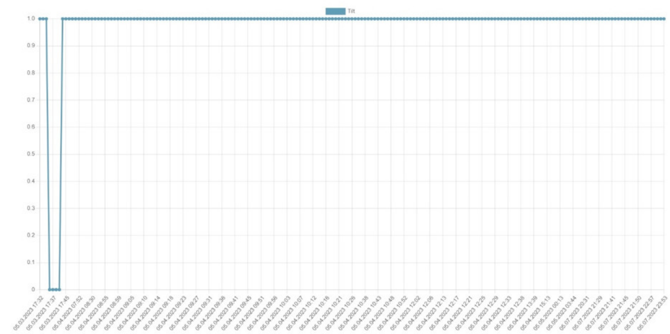
Stamp (id)	Sensor 1 (degree Celsius)	Sensor 2 (percentage)	Sensor 3 (lux)	Sensor 4 (degree)	Sensor 5 (time)
1	23	67	210287	1	07:52:19
2	23	69	6368071	1	07:53:51
3	23	47	17706190	1	07:54:59
4	23	45	3733773	1	07:56:14
5	28	31	2071784	1	08:30:38
6	28	31	66937	1	08:31:39
7	28	31	1441261782	1	08:32:40
8	30	31	7941525	1	08:54:38
9	30	31	4604226	1	08:55:44
10	30	32	6705695	1	08:56:45
11	30	32	703375	1	08:57:52
12	30	33	343843	1	08:58:53
13	30	33	173072	1	08:59:52
14	30	34	7822857	1	09:00:53
15	30	33	64688530	1	09:01:58
16	31	34	1107857	1	09:04:35
17	31	33	3076329	1	09:05:35
18	31	33	6727130	1	09:06:42
19	31	33	534516	1	09:08:13
20	31	32	2068191	1	09:09:13
21	31	32	5927012	1	09:10:12
22	31	31	238214	1	09:11:17
23	31	30	6511868	1	09:12:23
24	31	31	3081919	1	09:13:30
25	31	30	6343686	1	09:14:31
26	31	30	3612867	1	09:15:35
27	31	29	4198399	1	09:16:35
28	31	29	6442627	1	09:17:43
29	31	30	6517466	1	09:18:53
30	31	30	6562952	1	09:20:03
31	31	30	3118058	1	09:21:06
32	32	30	6231040	1	09:22:08
33	32	29	726672	1	09:23:31
34	32	29	2550362	1	09:24:34
35	32	30	24414	1	09:25:33
36	32	30	267643	1	09:26:31
37	32	29	1125983	1	09:27:28
38	32	29	745514	1	09:28:27
39	32	28	23516	1	09:29:26
40	32	28	1035640	1	09:30:25
41	32	28	921583	1	09:31:24
42	32	28	1431	1	09:32:23
43	32	28	5826174	1	09:33:23
44	32	28	9994901	1	09:34:25
45	32	28	2106588	1	09:36:58
46	33	28	1527213	1	09:38:19
47	33	28	18036	1	09:39:18
48	33	28	1770014	1	09:40:19
49	33	28	455	1	09:41:17
50	33	28	653873	1	09:42:16
...	...	...	...	...	...

Source: Authors.

The data captured by the sensors along the route are presented in Figures 4, 5 and 6.

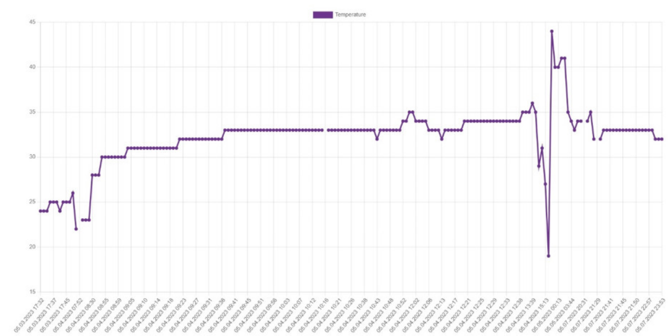
The device and the software were developed specifically for the purpose of this experiment. They are both economical, efficient and reliable. This system can be useful to the country through which the containerized cargo is transported, as well as to carriers, dispatchers, forwarders, insurers, owners and/or potential buyers of the cargo. It can be used as an embedded or confidential control system for other commercial solutions in this area. This can greatly contribute to a more efficient functioning of the security sector, especially in the monitoring of dangerous or suspicious cargo.

Figure 4: A sample of tilt sensor readings.



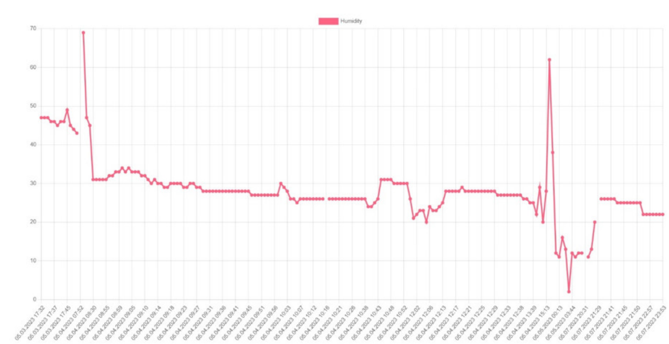
Source: Authors.

Figure 5: A sample of temperature sensor readings.



Source: Authors.

Figure 6: A sample of humidity sensor readings.



Source: Authors.

5. Security issues and measures.

The dispatcher and end-user deal with the web-based application, which is a part of the proposed freight container tracking system. Therefore, the whole system is exposed to all types of common Internet-based cybersecurity risks. Some IT security management measures that can help mitigate these threats are briefly presented, since cybersecurity is an important segment of the system overall proper functioning and high reliability. In other words, it is advisable to consider and implement the following precautionary mechanisms [24,25].

Encryption. Encryption includes cryptography mechanisms for scrambling data before sending, and then decoding it at recipient side. Commonly, encryption includes a pair of public and private keys. In this setting encryption can be used in files transmission between the dispatcher and end-user or cargo owner, for instance. More precisely, the file with data on container position and status can be scrambled and connected with the dispatcher's public key. After transmission, on the recipient side, only the dispatcher or the end-user's private key can unscramble it.

Firewall. A firewall is as a gatekeeper, which defends the system from intrusion. It scans the traffic and enables authorized data transfers into and out of the network. It can be dedicated host or router with the appropriate, network protection software. In the analyzed case of the container tracking system, firewall should be a dedicated software installed on the server side.

Preventing Denial of Service (DoS) attacks. DoS assaults can affect: the victim's site, the victim's Internet Service Provider (ISP), and the sites of so-called 'zombie' computers. At the victim's web site (dispatcher/end-users' one in the considered system) are recommended a backup server and network connections. At the ISP, monitoring and blocking traffic spikes is required, along with filtering spoofed IP addresses. Security must be coordinated with network providers. At the potential 'zombie' machines, the security policies must be set and enforced. Potential 'zombie' machines should be scanned regularly for *Trojan horse* programs and vulnerabilities (which is beyond our scope in the considered scenario). However, the dispatcher and end-users should be reminded not to open .exe mail attachments to prevent their computers becoming 'zombies'.

Virus defenses. Installing and updating antivirus software on both client and server sides is required. Some corporations as McAfee (VirusScan) and Symantec (Norton Antivirus) offer network versions of antivirus programs, aimed to protect ISPs and their customers. Furthermore, some companies combine virus protection with firewalls, web security, and suspicious traffic halting features. Both options might be useful for protecting the proposed container tracking system.

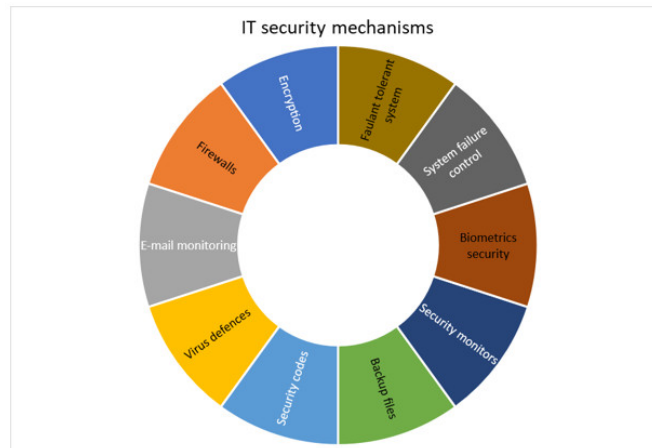
Security codes. A multiple password system, which includes user ID, password, and unique file name, is very important in ensuring system integrity. Such secured multiple password system is applied in the proposed container tracking system.

Backup files. Backup files are duplicate files of data or programs. Files can be protected by storing copies from previous periods. If current files are destroyed, the files from previous time frames can be used to reconstruct current files. So, within this context, the dispatcher/users should regularly backup the data as a precautious measure.

Security monitors. These are programs that control the operation of computer devices and networks to protect them from unauthorized use, fraud and destruction. They offer security mechanisms, which enable access only to authorized users. This is the case with here proposed secured web-based container tracking system, which has accompanied the security monitoring program.

Biometric security. It includes the unique identification via voice verification, fingerprints, hand geometry, signature dynamics, keystroke analysis, passive iris scan, retina scanning, face recognition, etc. Biometric control units use dedicated sensors to measure and diagnose a biometric profile of a person, who approaches the system and intends to use its resources. These secured access mechanisms can be applied in the proposed tracking system.

Figure 7: A container tracking system: IT security management tools.



Source: Authors.

Some general recommendations. In terms of network security management, dispatchers and end-users of the proposed container tracking system should use and frequently update antivirus and firewall software to keep destructive programs off their computers and virtual smart phones. Additionally, they should use passwords that are difficult to guess, containing a mixture of numbers and letters, and change them frequently; the latest versions of web browsers, e-mail software and other programs; a security program that gives control over cookies that send information back to websites; firewall software to screen traffic if they use a digital subscriber line (DSL) or cable modem to connect to the Internet, and the like.

It is planned to conduct similar experiments with the proposed device in tracking cargo containers in sea transport, after obtaining the necessary ethical approval. There are also plans to use this device to track a batch of containers in road/rail and sea transport. These plans need to be supported by appropriate IT security measures, as cybersecurity intrusions and data breaches are becoming the biggest obstacle to doing business (or research) online. Therefore, this section has provided a brief overview of IT security mechanisms and tools. Of course, the developers and users of this system, and similar ones, will have to choose IT security management measures and appropriate tools in accordance to their real needs and preferences.

Conclusions.

The article presents an electronic device and its back-end info-communication system for tracking a freight container. The proposed tracking system was tested in onshore transport, so far. The route of the container and its state of temperature, humidity, light and tilt (motion), in close to real time, have been scanned and presented to the dispatcher and end-users. The Raspberry Pi is a core of the hardware, while Python is used for developing the secure web-based application and enabling communication with the data base and users . The same device and software will be tested at sea, where the real setting is different, and the connection is not as fast and reliable as ashore. Research ethics approval is currently being sought to deploy the instrument and to 'clone' the experiment at sea.

Regarding more advanced approaches to tracking containers on land and at sea compared to the one presented in the paper, it should be noted that maritime cluster gives priority to costs and benefits while adopting emerging technologies. Consequently, the implementation of Physical Internet (PI) and blockchain technologies, for example, is currently down-at-heel in maritime domain. This lagging process is additionally influenced by the lack of knowledge and understanding across the sector of the advantages and disadvantages of digital technologies. Besides, there is a need to develop regulations that will govern PI and blockchain applications on a global scale. Asymmetric information sharing upstream, and downstream supply chains, also, needs to be addressed. All these are of concern to key players in global trade, but even more so to those further down the supply chains. Bearing all this in mind, the mainstream implementation and adoption of PI and blockchain in tracking freight containers in land and maritime transport, will not happen soon. It will take time, a higher level of knowledge and business culture, and the appropriate engagement of all relevant stakeholders. Therefore, an affordable, 'do-it-yourself' based experimental device for freight container movement and status tracking, which is proposed here, can stimulate further and deeper research in this area, encompassing various cybersecurity threats and countermeasures.

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